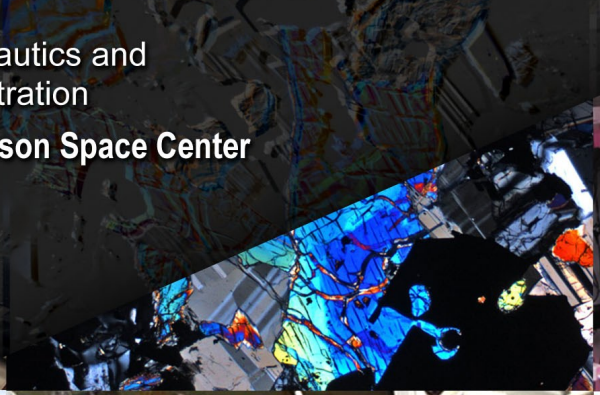
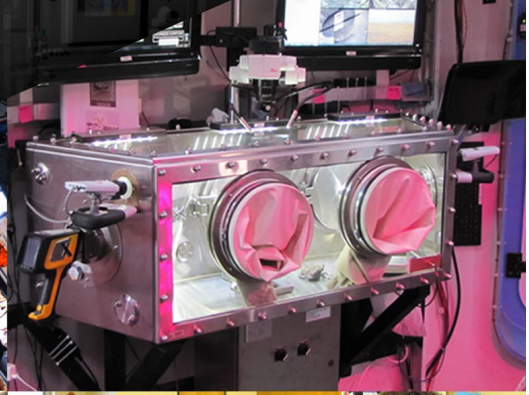
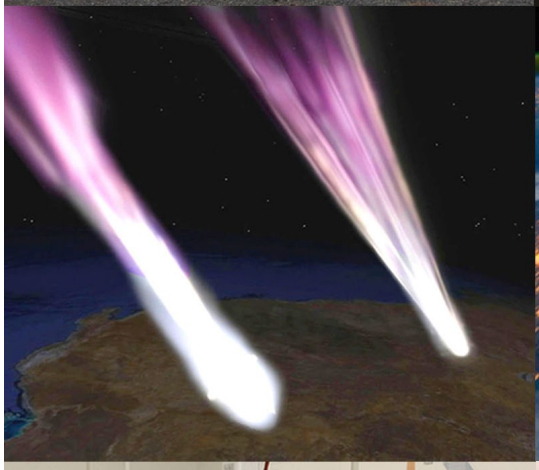
National Aeronautics and Space Administration

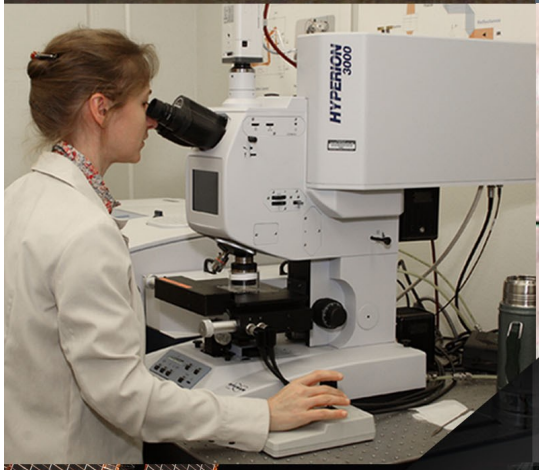
Lyndon B. Johnson Space Center

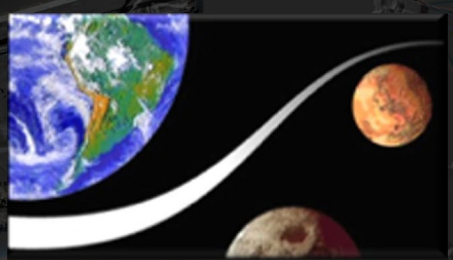






Research and Applied Science Facilities and Capabilities Guide





ARES

Astromaterials Research & Exploration Science

May 2014

Welcome to the Johnson Space Center

Johnson Space Center's science teams have successfully accomplished many of the nation's most complex exploration-related projects. The Center has developed and refined advanced techniques in research and analysis that are applicable to a broad variety of investigations—from Earth and space science, materials testing, and image science and analysis to the very nature of the formation of the solar system. Through this ongoing refinement, Johnson Space Center continues to expand its world-class capabilities, which include an expert work force, natural infrastructure, unique facilities, flexible project management, and a proven operating system.

Table of Contents

Overview

The NASA Johnson Space Center (JSC) is uniquely positioned to provide research and applied science expertise and capabilities to a wide variety of basic and applied science applications. Capabilities are available in the areas of research and analytical services, science consulting, image analysis, and hypervelocity impact technology. This guide describes the scientific and analytical capabilities that are currently available and is divided into four categories represented by the color scheme presented below.

Image Science and Analysis

Photogrammetry

High-Precision Motion Tracking

Imagery Enhancements and Restoration

Imagery Simulation & Data Visualization

Imagery Inspection and Surveys

Imagery Acquisition Planning and Imagery Operations Management

Science Consulting Services

Basic and Applied Research

Experimental Design and Analysis

Curation and Data Management

Education Outreach and Training

Science Mission Planning

Hypervelocity Impact Technology

Micrometeoroid and Orbital Debris (MMOD) Risk Assessment

MMOD Shield Design

MMOD Hypervelocity Impact Testing

MMOD Hypervelocity Simulation

MMOD Postflight Impact Inspection

Research and Analytical Services

Scanning Electron Microscopy

Transmission Electron Microscopy

Focused Ion Beam

Electron Microprobe

Mass Spectrometry

X-Ray Diffraction

Mars, Moon, Meteorite Evolved Gas Analysis Laboratory

Organic Microprobe

Experimental Impact Laboratory

Optical Measurement Center

Doing Business With Us

We have developed customer-friendly agreements to streamline business relationships and are eager to share our unique facilities and expertise with new customers. We invite your inquiries regarding application or adaptation of our capabilities to satisfy your special requirements. Briefings on general or specific subjects of mutual interest can be arranged on location at JSC or at your business site.

There are two paths established for obtaining our services, depending on your organization type. The steps below summarize the typical process for planning and conducting science and analysis activities within the Astromaterials Research and Exploration Science (ARES) Directorate at JSC.

Commercial Partners

1. Commercial Partner contacts the JSC representative listed below to inquire about our services.
2. JSC will provide an initial cost and schedule estimate.
3. If the estimated cost and schedule are acceptable, a Space Act Agreement will be drafted.
   Note: *Commercial Partners may be able to use an existing umbrella agreement.*
4. Once the agreement is signed, funding must be submitted to the NASA JSC Finance Office in order to proceed with work.

Government Partners

1. Government Partner contacts the JSC representative listed below to inquire about our services.
2. JSC will provide an initial cost and schedule estimate.
3. If the estimated cost and schedule are acceptable, an interagency agreement or reimbursable agreement will be drafted.
4. Once the agreement is signed, a valid purchase request, such as a Military Interdepartmental Purchase Agreement, must be submitted by an authorized certifying officer.

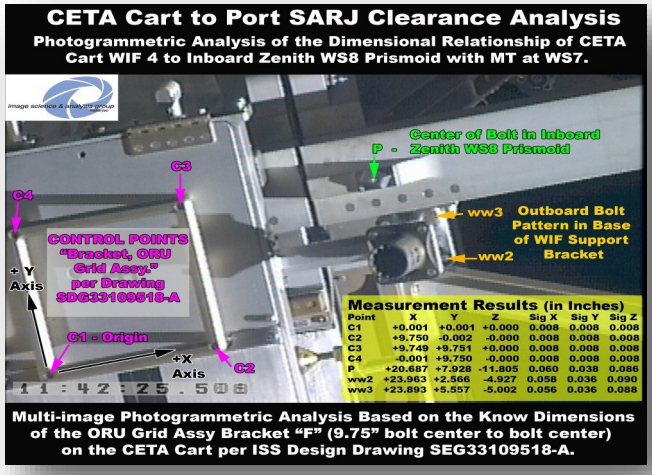
Contact Information

General Inquiries	Gregory J. Byrne Deputy Director, Astromaterials Research and Exploration Science Phone: 281-483-0500 E-mail: gregory.j.byrne@nasa.gov

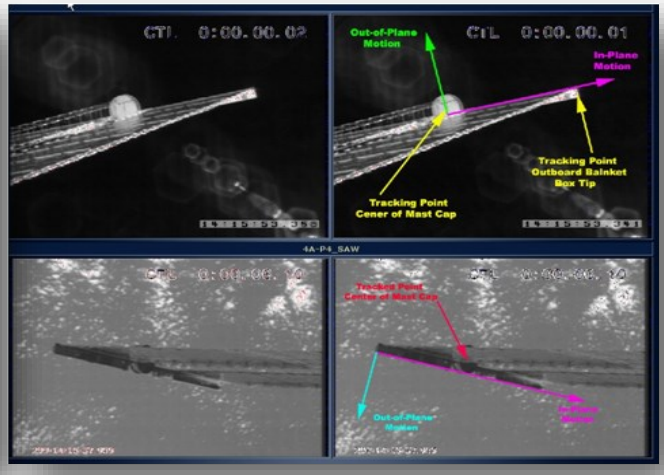
For assistance or additional information about JSC, please visit: http://ares.jsc.nasa.gov

Image Science and Analysis

JSC provides expertise in scientific and engineering analysis of imagery. Specialty areas include photogrammetry, high-precision motion tracking, imagery enhancement and restoration, data visualization, imagery-based inspection and surveys, imagery acquisition planning, and imagery operations management.

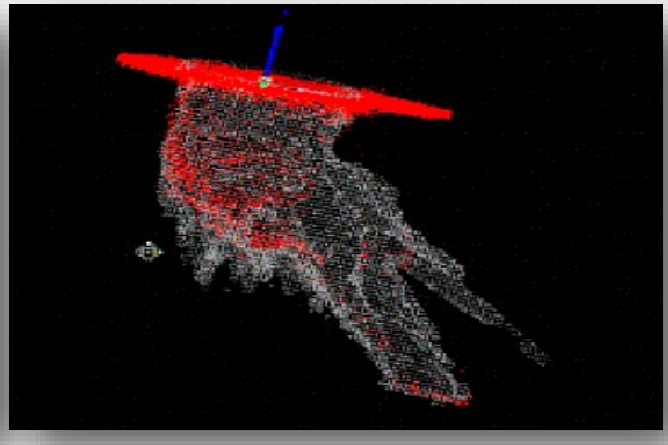


Photogrammetry

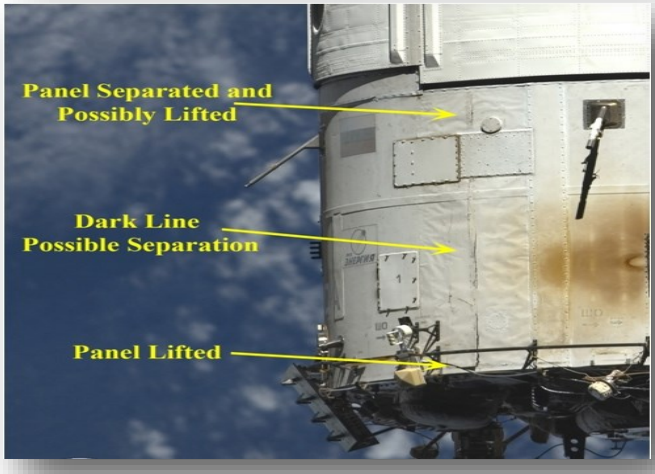


High-Precision Motion Tracking

Image Enhancement and Restoration



Data Visualization



Imagery Inspection and Surveys

Imagery Acquisition Planning and Management

Image Science and Analysis

Photogrammetry

- Photogrammetry is the science of applying image based measurement techniques to determine the position and shape of objects from two or more images (film, video or digital images) acquired from different perspectives
- Photogrammetric techniques from both aerial mapping (stereo analysis) and close range industrial measurement (convergent analysis) are used to design custom, non-traditional approaches for each task
- Specialization in the measurement of natural features and one of a kind applications which are not suitable for many of the turn-key measurement systems which rely on the extensive use of artificial targets

Applications

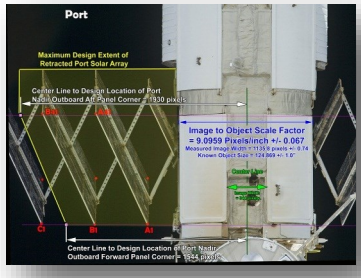
- Single Image Quantitative Analysis
  - Two dimensional size
  - Areas in the plane of the image
  - Historical change analysis
- 3D Photogrammetric Analysis
  - Size – length, width, height
  - Area and volumes
  - Surface shape modeling
  - Relative geometry and clearance
- 6D Photogrammetry from Video
  - 6D (X,Y,Z, roll, pitch and yaw)
  - Velocity
  - Acceleration
  - Trajectory
- Camera Characterization
  - Determine effective focal length, principal point and Simultaneous Multiframe, Analytical Calibration (SMAC) model lens distortion parameterization
  - Resampling imagery to remove lens distortion

Tools

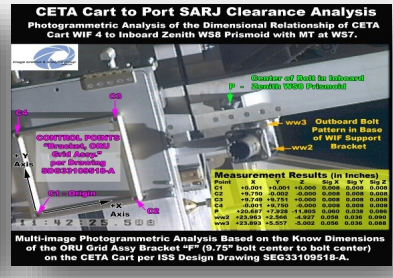
- Cardinal systems photogrammetry software, FotoG, PhotoModeler, Austrails

JSC Experience

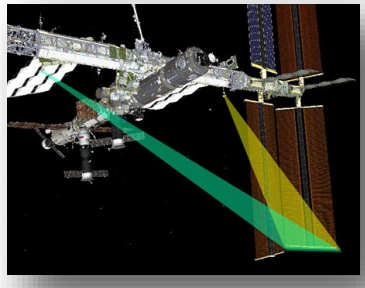
- Space Shuttle damage assessment
- Measuring ISS solar array and radiator motion for structural load modeling

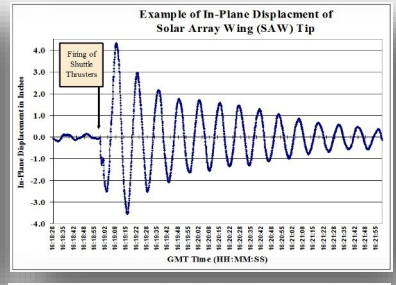


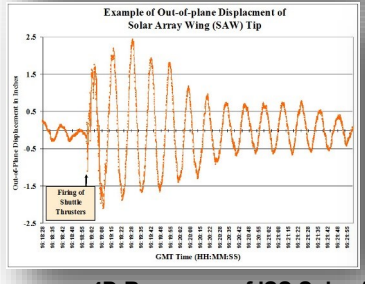
Single Image Analysis

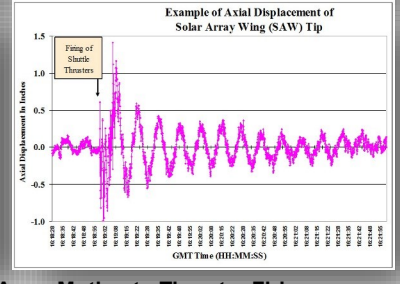


3-D Clearance Analysis

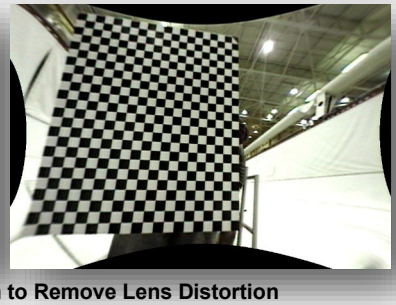








4D Response of ISS Solar Array Motion to Thruster Firing



Camera Characterization to Remove Lens Distortion

Image Science and Analysis

High-Precision Motion Tracking

- Determine the image location with sub pixel accuracy of a moving object of interest in each frame of a video sequence, using automated or semi-automated techniques without the prerequisite of artificial targets
- Tracking the motion of objects in imagery by finding the 2D coordinates of pixels on an image sequence

Applications

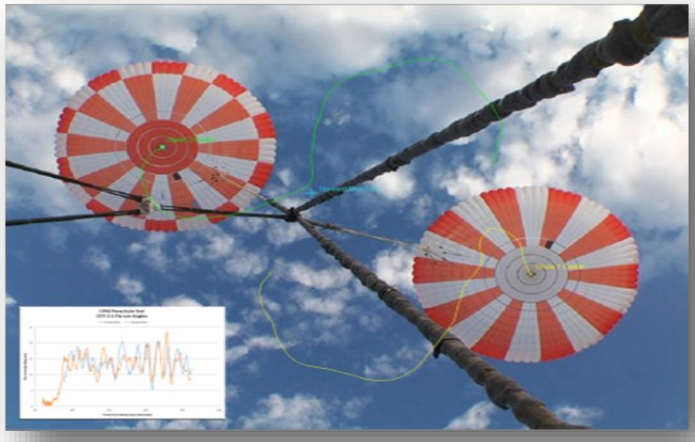
- ISS appendage response to dynamic events for structural loads analysis
- ISS hardware jettison trajectories
- Orion parachute performance analysis

Tools

- Trackeye
- NanoTrack
- WinAnalyze

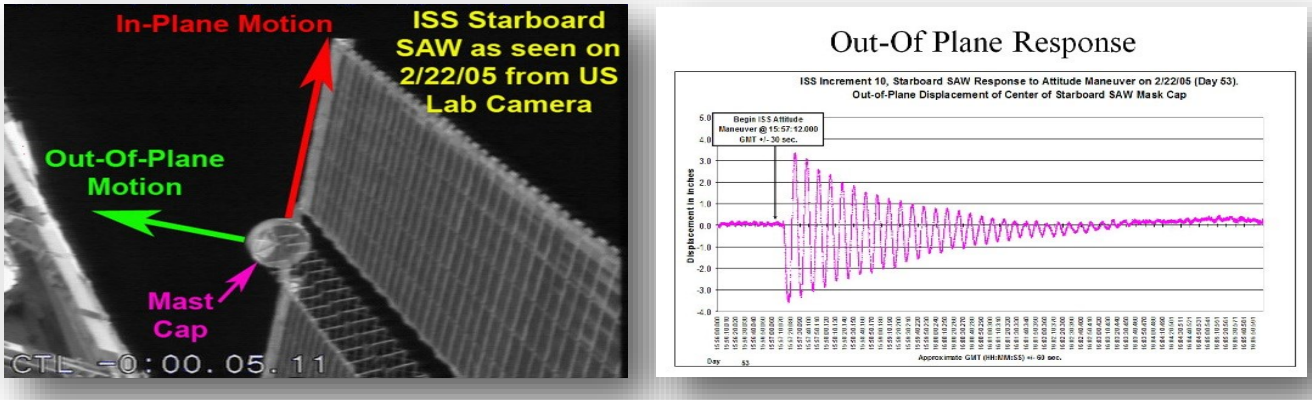
JSC Experience

- Analysis of Orion Capsule Parachute Assembly System (CPAS) to determine fly-out angles, chute diameters, and torque
- Initial trajectory determination for jettison of Early Ammonia Servicer (EAS) and Video Stanchion Support Assembly (VSSA)
- Tracking of ISS solar array and thermal radiator response to thruster firings for analysis of structural loads
- Verification and modeling of solar array bending due to longeron shadowing



Parachute Inflation Time and Fly-Out Angle Analysis

Initial Trajectory Determination for Jettison



Analysis of Solar Array Motion over Time

Image Science and Analysis

Imagery Enhancements and Restoration

- Imagery enhancements bring out features that are not readily visible. A suite of image enhancement techniques are used to maximize the amount of useful information that can be gleaned from video or still imagery
- Restoration involves using image processing methods to correct for image degradation caused by issues such as motion blur or camera focus

Applications

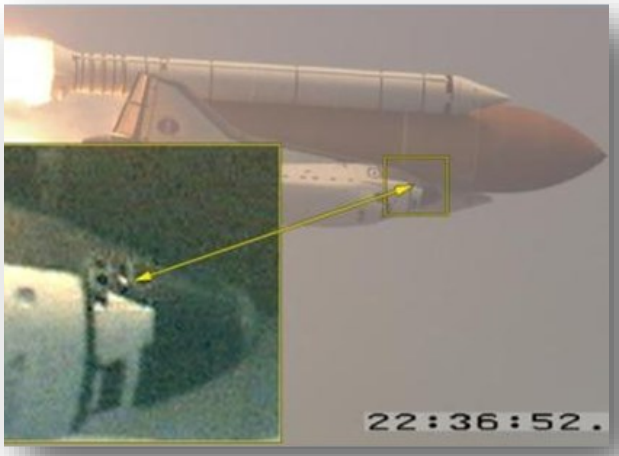
- Enhancement of dark or shadowed external tank after Orbiter separation
- Enhancement of debris seen during launch and ascent imagery
- Enhancement of suspect areas on ISS to detect damage or other anomalies

Tools

- Photoshop Extended version
- Image-Pro Plus

JSC Experience

- Space Shuttle and commercial cargo demonstration launches
- ISS surveys and inspections
- Law enforcement



Enhancement of Tyvek cover on Orbiter Thruster

Photo of External Tank from Orbiter Umbilical—Unenhanced

Photo of External Tank from Orbiter Umbilical—Enhanced

Image Science and Analysis

Imagery Simulation and Data Visualization

Dynamic simulation, realistic imagery asset output, previsualization, and display of 3D imagery, data, and computer-aided design models enhance engineering and scientific understanding.

Applications

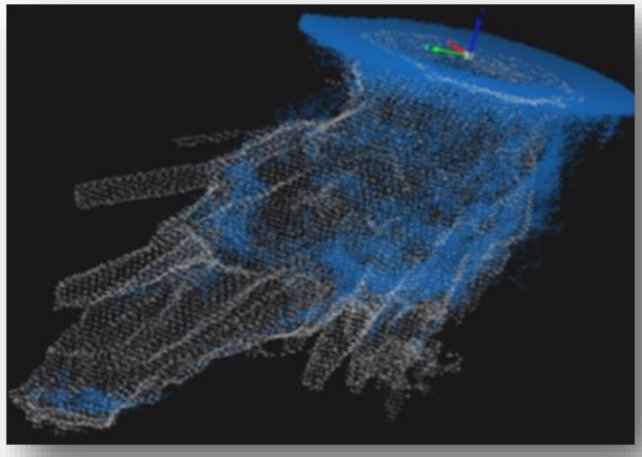
- Previsualization of ground, onboard, and air-based camera views for system optimization
- 3D visualization of hypervelocity impacts to Orion Thermal Protection System (TPS) tiles
- Simulation of dynamic mission events and previsualization of imagery for photogrammetric analysis planning

Tools

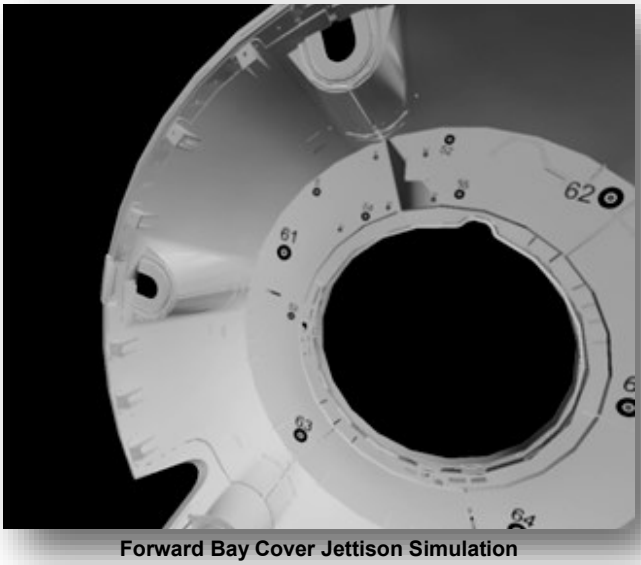
- Innovmetric PolyWorks
- Autodesk 3ds Max
- VrTwo, VrCr
- Proprietary JSC-developed software

JSC Experience

- Assessment of Orion TPS focused inspection methods
- Planning camera tracking for launch confiigurations



3D Visualization of Hypervelocity Impacts to Orion TPS Tiles



Forward Bay Cover Jettison Simulation

Launch Simulation from Ground Cameras

Image Science and Analysis

Imagery Inspection and Surveys

Use of imagery from robotic, fixed, or handheld cameras to detect and characterize damage or other anomalies.

Applications

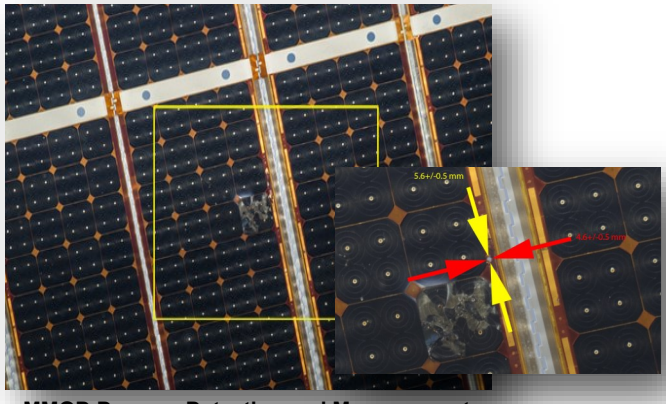
- Detecting damage to, or degradation of, hardware surfaces
- Detecting out-of-configuration hardware

Tools

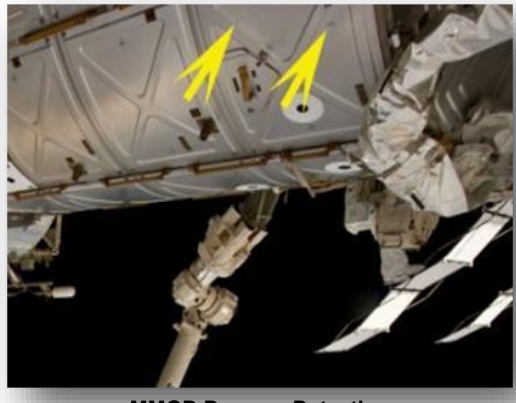
- MATLAB ® imagery inspection tools (Baseline, Browse, Blink)
- Photoshop, Irfanview, Image-Pro Plus
- ISS Imagery Inspection Management System (IIIMS)

JSC Experience

- ISS survey planning
- ISS external inspections
- EVA sharp edge tracking
- Planning for Orion Micrometeoroid and Orbital Debris (MMOD) damage detection

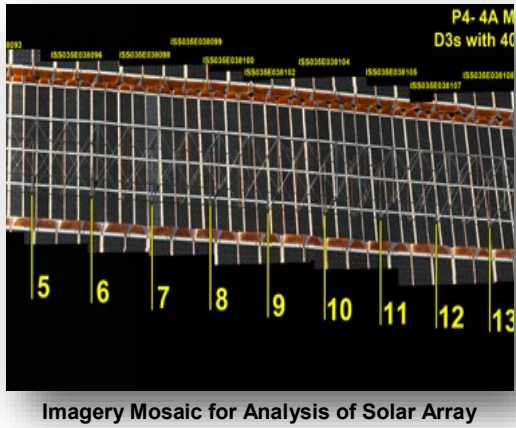


MMOD Damage Detection and Measurement



MMOD Damage Detection

Analysts Reviewing Imagery



Imagery Mosaic for Analysis of Solar Array Center Mast

Image Science and Analysis

Imagery Acquisition Planning and Imagery Operations Management

Development of comprehensive image acquisition plans to obtain all imagery required to support an analysis task. Considerations for planning include camera locations, camera perspectives, scene lighting, camera lenses, exposure settings, frame rates and depth of field. Real-time and post-mission management of imagery acquisition and distribution.

Applications

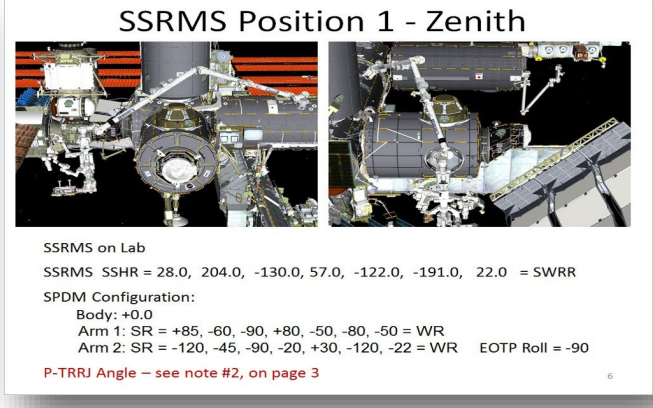
- Motion analysis using photogrammetry
- Analysis of jettisoned object or debris trajectories
- Clearance studies
- Lighting studies
- Leading multi-center, multi-agency imagery teams in the collection, handling and distribution of imagery

Tools

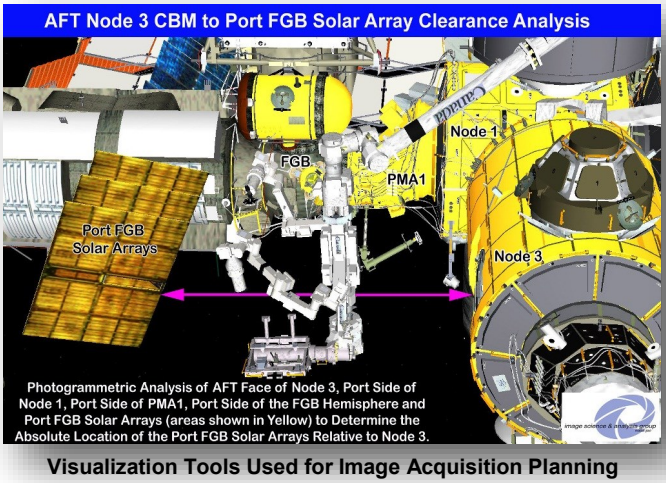
- Dynamic Onboard Ubiquitous Graphics (DOUG)
- Launch viewer tools
- Lighting analysis from JSC Graphics Research and Analysis Facility (GRAF)

JSC Experience

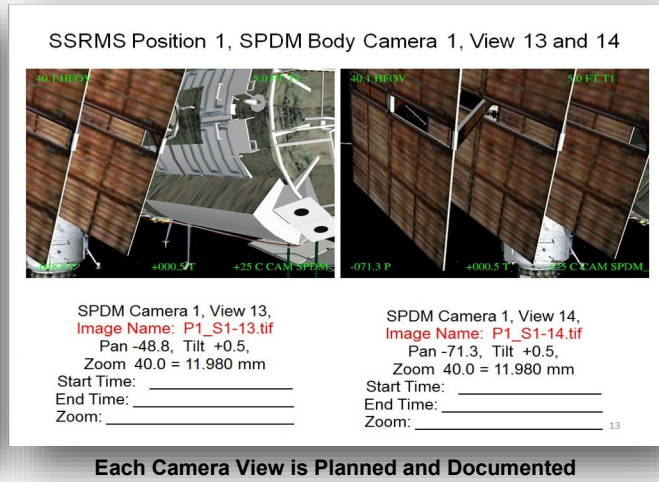
- Video acquisition of ISS solar array motion in response to thruster firings for analyses for structural loads
- Space Station Remote Manipulator System (SSRMS) imagery of on-orbit ISS hardware for clearance analysis
- ISS external camera imagery of jettisoned hardware for trajectory analysis
- Launch imagery performance reviews for Orion, Heavy Lift, and Commercial Orbital Transportation Services (COTS)



Camera Platform Locations Specified



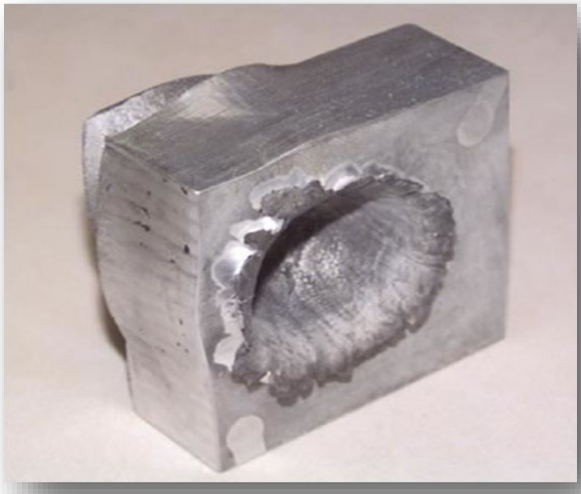
Visualization Tools Used for Image Acquisition Planning



Each Camera View is Planned and Documented

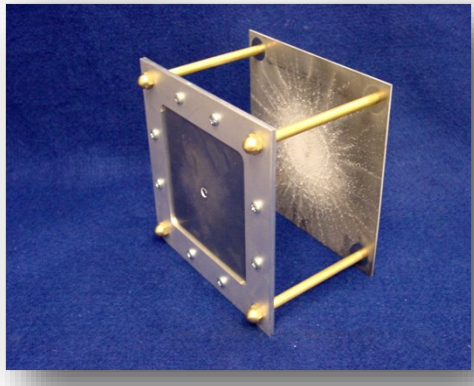
Hypervelocity Impact Technology

JSC provides expertise in hypervelocity impact technology including testing, materials analysis, and design and development of shielding concepts. Specialty areas include MMOD shielding design, hypervelocity impact testing, hypervelocity impact computer simulation, MMOD shield ballistic limit determination, and MMOD impact and penetration risk assessment.

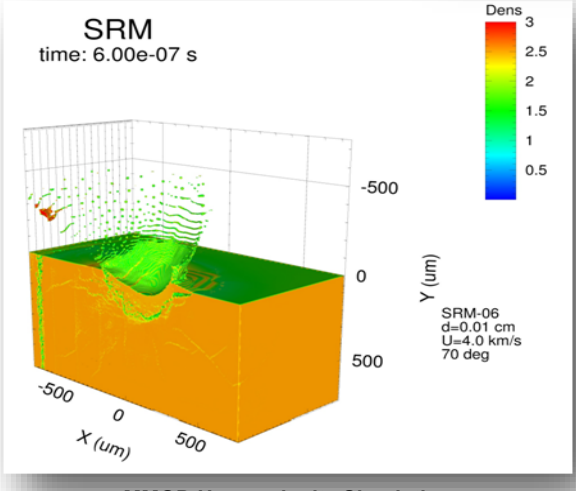


MMOD Hypervelocity Impact Testing

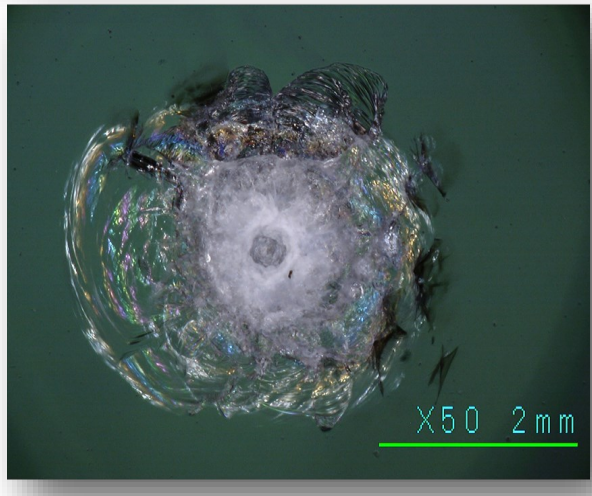
MMOD Risk Assessment



MMOD Shield Design



MMOD Hypervelocity Simulation



MMOD Postflight Impact Inspection

Hypervelocity Impact Technology

MMOD Risk Assessment

Analyzing the risk of micrometeoroid and orbital debris impacts to spacecraft.

Applications

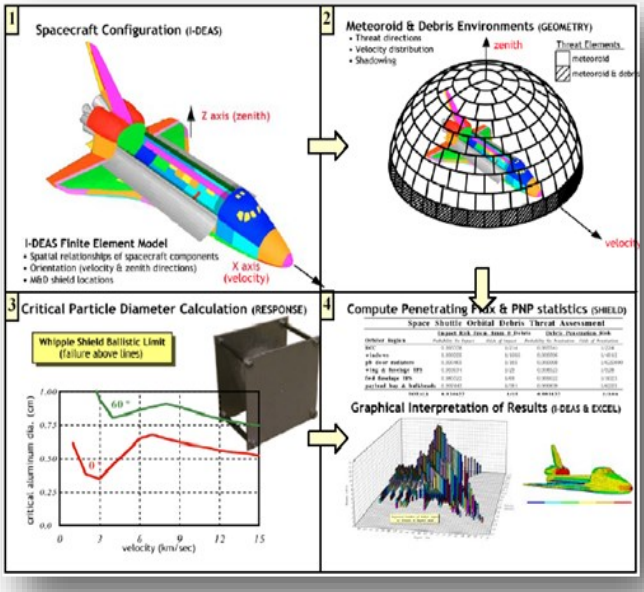
- Assessment of spacecraft MMOD requirements
- Optimization of MMOD shield size and location
- Evaluation of the effect of varying mission parameters (altitude, inclination, attitude, launch date)

Tools

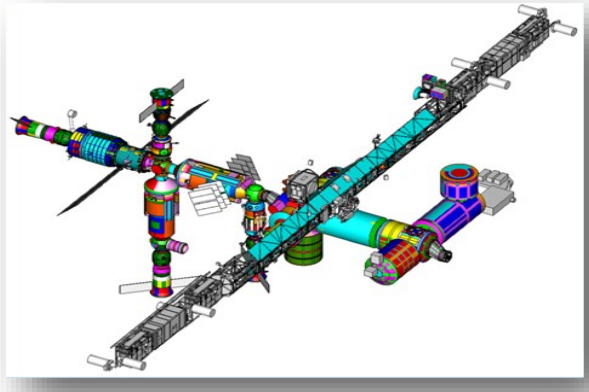
- Bumper MMOD risk analysis code
- Orbital Debris Engineering Model (ORDEM)
- Meteoroid Environment Model (MEM)
- Finite element modeling of spacecraft

JSC Experience

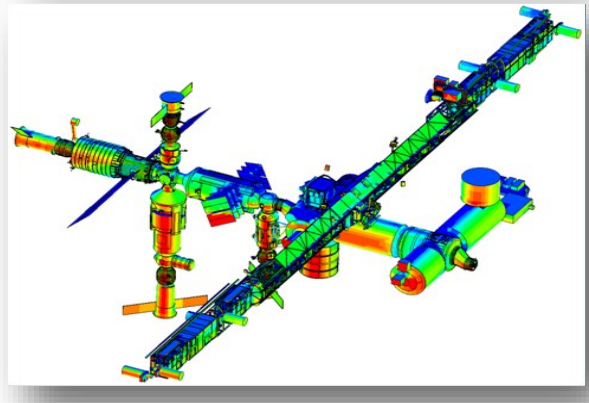
- Space Shuttle Orbiter
- International Space Station
- Orion Crew Module, Service Module, and docking adapters
- COTS Program vehicles
- Extravehicular Mobility Unit (EMU) space suit
- Commercial satellites



Shield Design and Risk Assessment Process Overview



ISS MMOD Shield Locations



ISS MMOD Impact Risk Contour

Hypervelocity Impact Technology

MMOD Shield Design

Applying knowledge of hypervelocity impact shielding to spacecraft design.

Applications

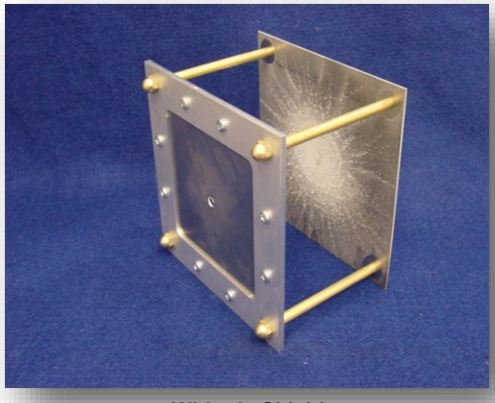
- Developing shielding configurations to meet spacecraft MMOD requirements
- Optimizing spacecraft shield design for weight and space constraints
- Augmenting existing spacecraft structures to protect against MMOD impacts

Tools

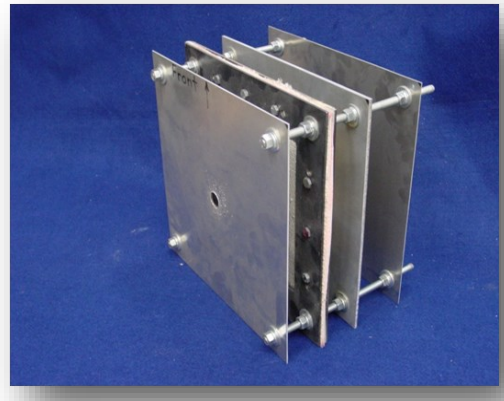
- Database of thousands of hypervelocity impact tests

JSC Experience

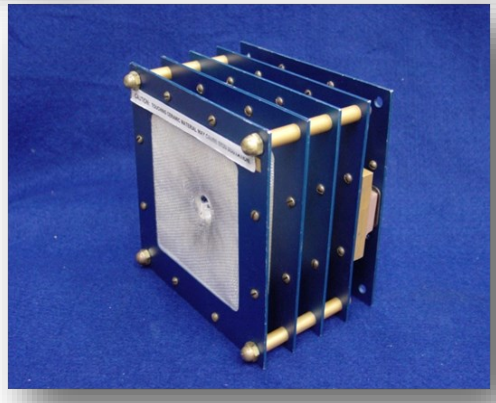
- Implementing MMOD shields in the early stages of spacecraft designs
  - Whipple shields
  - Stuffed Whipple shields
  - Multishock shields
- Retrofitting MMOD shields into existing spacecraft designs
  - Soyuz Orbital Module and Progress Cargo Module augmentation
  - ISS Service Module conformal shields
  - Space Shuttle radiator doublers



Whipple Shield



Stuffed Whipple Shield



Multishock Shield

Hypervelocity Impact Technology

MMOD Hypervelocity Impact Testing

Evaluating the performance of spacecraft structures by simulating MMOD impacts.

Applications

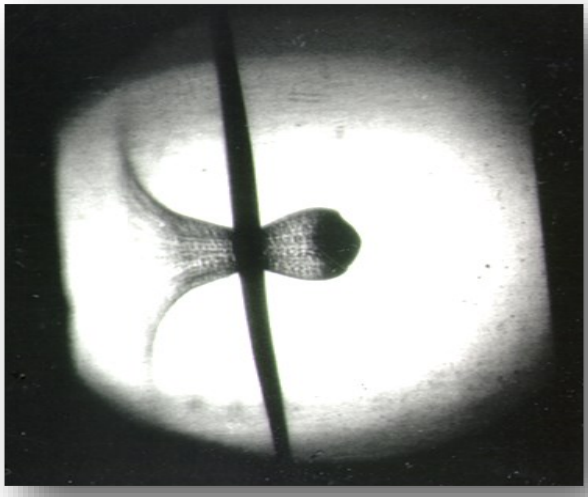
- Development of MMOD shield ballistic limit equations for use in risk analysis
- Validation of MMOD shield performance
- Characterization of MMOD impact damage

Tools

- Two-stage light gas guns at White Sands Test Facility (WSTF)
  - 0.17 caliber, 0.50 caliber, and 1.0 inch barrels
  - Velocities up to 7.5+ km/s
  - High-quality diagnostic equipment
  - High-speed cameras (2 million frames per second)
  - Flash X-ray systems
  - Laser velocity measurement systems
- Inhibited Shaped-Charge Launcher (ISCL) at Southwest Research Institute (SwRI)
  - Velocities up to 11.0+ km/s

JSC Experience

- More than 25 years of hypervelocity testing experience
- More than 10,000 impact tests performed and analyzed



Shadowgraph of Debris Cloud from Hypervelocity Impact Test

Hypervelocity Impact Test Range at WSTF

Hypervelocity Impact Technology

MMOD Hypervelocity Simulation

Computer simulation of hypervelocity impacts.

Applications

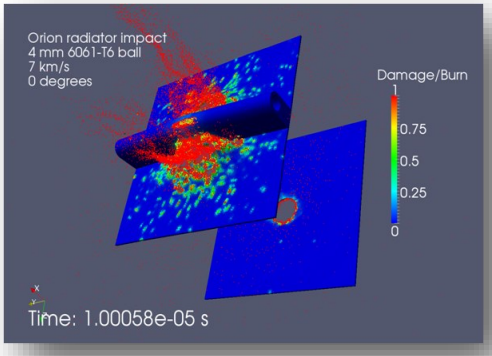
- Refinement of test parameters for optimization hypervelocity impact testing
- Simulation of hypervelocity impacts at speeds higher than can be tested
- Estimation of impact conditions for observed on-orbit damages
- Computation of dynamic loads generated as a result of an impact

Tools

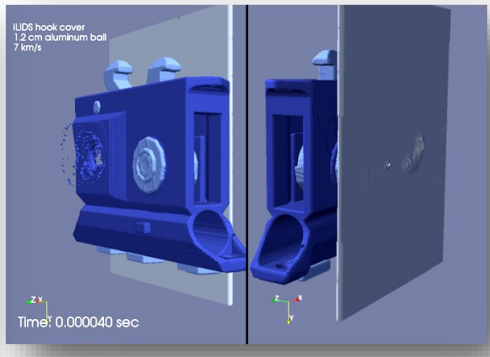
- Hypervelocity Impact Test (HVIT) high-performance computer with 120 processors
- CTH finite difference code (Sandia National Laboratories, Albuquerque)
- EPIC finite element code with conversion of eroded elements to Smooth Particle Hydrodynamics (SPH) particles Tank Automotive Research, Development, and Engineering Center (TARDEC)
- EXOS finite element code with conversion of eroded elements to SPH particles (University of Texas at Austin)

JSC Experience

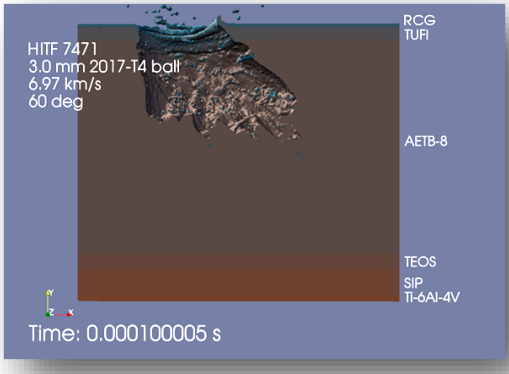
- Orion test and analysis services
- Simulation of STS-128 radiator impact
- Calculation of the air blast loads from a large orbital debris particle impact on ISS



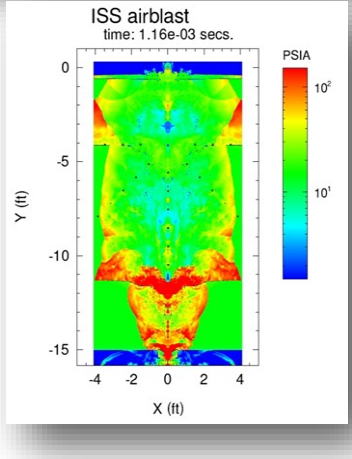
Orion Radiator Fluid Line Perforation



Penetration of the International Low-Impact Docking System (iLIDS) Tunnel Through the Hook Cover



Orion Thermal Protection System (TPS) Tile Impact Test Simulation



Air Blast From a Large Particle Impact in the US LAB Aisle

Hypervelocity Impact Technology

MMOD Postflight Impact Inspection

Examining returned space-flown surfaces for MMOD impact damage and collecting damage measurements and residue samples to characterize the impact.

Applications

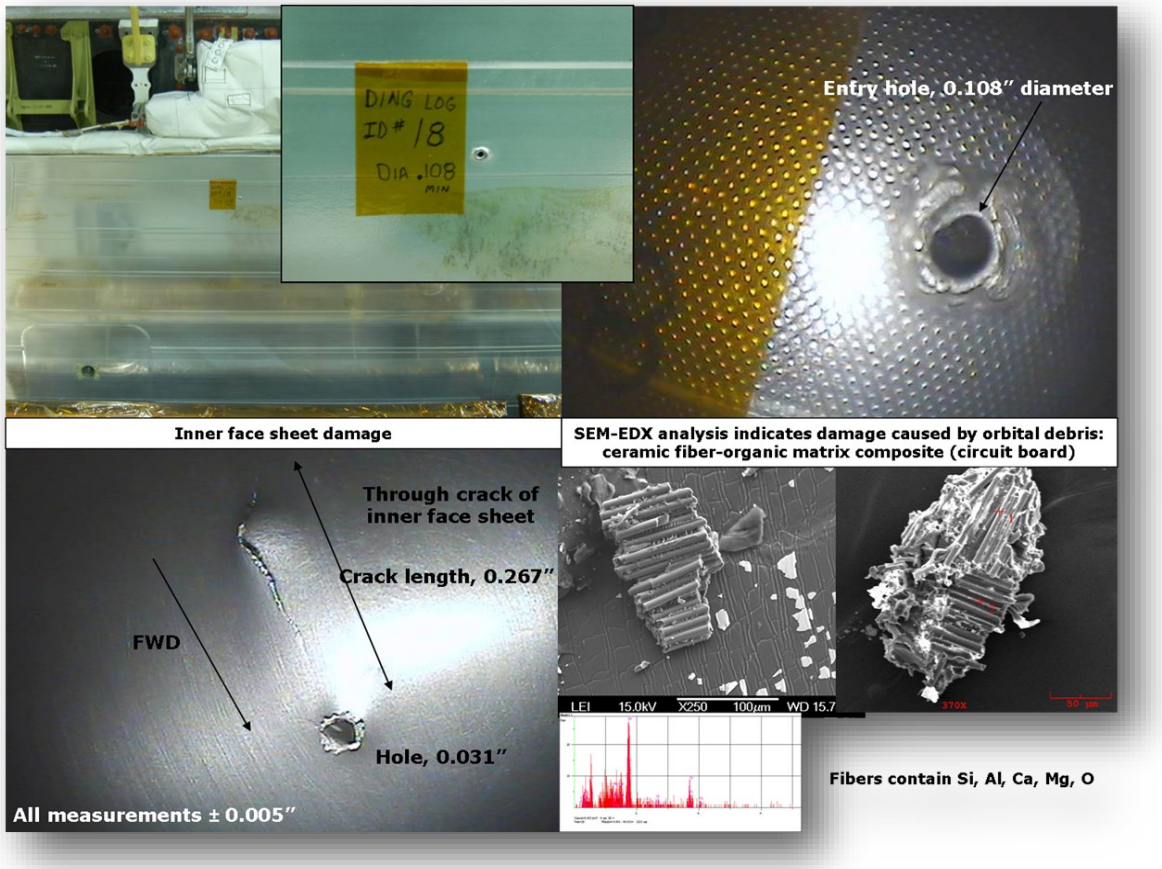
- Root-cause analysis of spacecraft component failure
- Refinement of MMOD environment models
- Population of historical on-orbit impact database

Tools

- Handheld digital microscope
- Digital micrometer
- Scanning electron microscope
- Energy Dispersion X-ray (EDX) spectroscopy

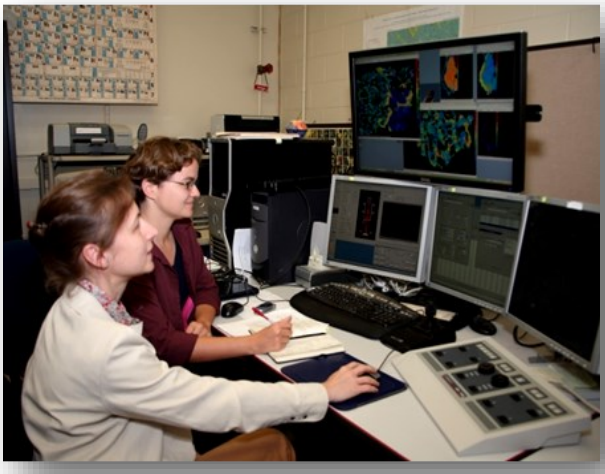
JSC Experience

- Space Shuttle Orbiter (windows, heat shield, radiators)
- ISS Multipurpose Logistics Module (MPLM)
- Returned ISS hardware components



Science Consulting Services

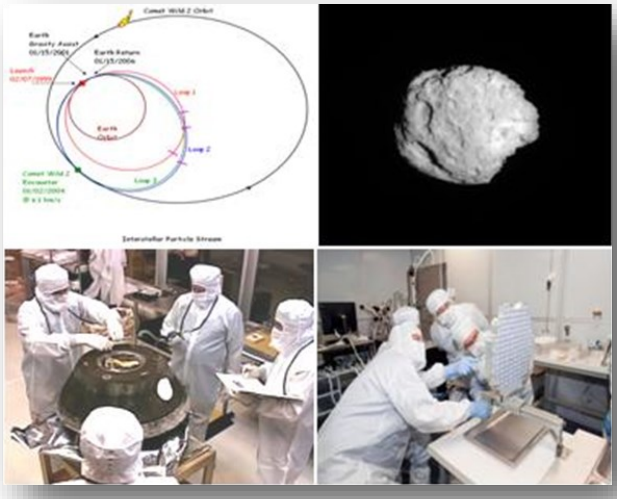
JSC provides expertise in basic and applied science concept development, methodology, science proposals, facilities and instruments, and research and development management. Specific expertise is available for the development of science proposals for astromaterials and planetary research, experiment design and instrumental analysis techniques, and curation of unique astromaterials samples and collections. Education and public outreach program training and development expertise is also available. JSC is actively involved in developing planetary science mission concepts and providing Earth imagery to the Earth science community.



Basic and Applied Research

Science Mission Planning

Education, Outreach and Training



Planetary Mission Science

Science Consulting Services

Basic and Applied Research

Designing experiments and writing proposals using scientific methodology to build logical, testable hypotheses; identifying appropriate field, laboratory, and simulation based techniques for data collection and analysis; and providing guidance on visualization and reporting of results in professional publications.

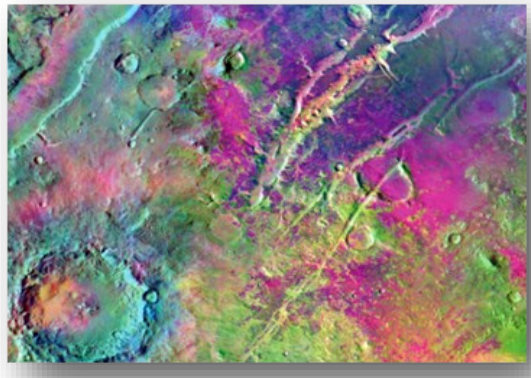
Applications

- Geology, geochemistry, physics, astronomy, astrophysics
- Planetary science and astrobiology
  - Moon, Mars, near-Earth objects, asteroids, and comets
- Earth system science
  - Hydrosphere, biosphere, atmosphere, geosphere, and cryosphere
- Characterization and interpretation of terrestrial, planetary, and solar materials
- Characterization of the low Earth orbit space environment, hazards, and risk assessment
- Terrestrial and planetary remotely sensed data acquisition, analysis, and interpretation
  - Optical multispectral and hyperspectral imaging, photogrammetry, radar, and Light Detection and Ranging (LiDAR)

JSC Experience

- Approximately 200 active research and operational scientists, analysts, and technicians
- Significant and sustained research grant funding from NASA, the National Science Foundation, and other agencies
- Strong record of publication in high-impact journals, such as *Science* and *Nature*
- Processes and products resulting in U.S. patents

Scientist Analyzing a Stardust Sample



Orbital Spectral Data of Mars

Sarychev Volcano Eruption as Photographed from the ISS

Science Consulting Services

Experimental Design and Analysis

Identifying and applying appropriate field, laboratory, and simulation-based techniques for data collection and analysis and providing guidance on data reduction, visualization, and reporting of results.

Applications

- Analysis and classification of terrestrial, planetary, and solar materials and space-exposed hardware
  - Scanning Electron Microscopy (SEM)/Transmission Electron Microscopy (TEM), Focused Ion Beam (FIB), mass spectrometry, electron microprobe, Laser-Induced Breakdown Spectroscopy (LIBS), X-Ray Diffraction (XRD), NanoSIMS, Thermal Ionization Mass Spectrometry (TIMS), Thermal and Evolved Gas Analysis (TEGA), Fourier Transform Infrared and Raman (FTIR) spectroscopy, and optical microscopy
- Terrestrial and planetary remotely sensed data analysis and visualization
- High-pressure materials fabrication and analysis
  - Piston cylinder and multi-anvil presses, 5–300 kbar, and up to 2500 °C capability
- Field surveys and data collection; planning, performance, and testing of field equipment
  - Visible through shortwave Infrared (IR) and thermal IR spectrometers, Handheld X-ray Fluorescence (XRF), and Forward-Looking IR (FLIR) cameras
- Hypervelocity impact and materials testing
- Laboratory and instrument operations and maintenance

Scientist Conducting Fourier Transform Infrared Spectroscopy

Focused Ion Beam Laboratory

Habitat Demonstration Unit during Desert RATS Analog Field Test

Science Consulting Services

Curation and Data Management

End-to-end consulting services for design, operation, and management of both physical sample and digital data curation facilities and databases.

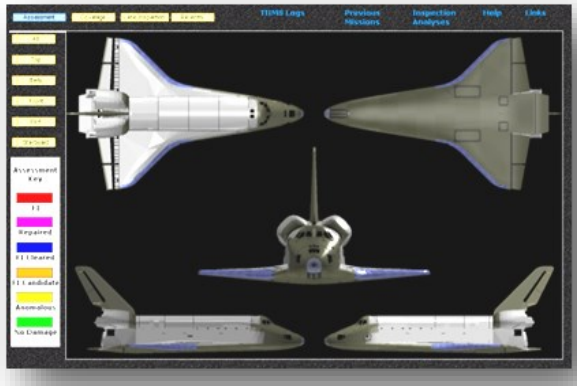
Applications

- Classification, processing, storage, and distribution of lunar rock, soil, and soil core samples; meteorites; cometary and interstellar particles; solar wind atoms; and stratospheric cosmic dust and orbital debris
- Processing, storage, and distribution of space-exposed hardware
- Maintenance of detailed processing logs and sample location tracking
- Design, construction, and operation of ISO class 3 to 10000 clean rooms
- Design, testing, and maintenance of digital databases and search interfaces
- Network and server configuration for delivery of large data volume, high-demand database services over secure local networks and global Internet

JSC Experience

- Curational support of the NASA lunar sample and Antarctic meteorite collections as well as Stardust and Genesis sample return missions
- Design and implementation of an online database for a historical lunar sample photograph collection
- Operational use of Imagery Management System software in Shuttle, ISS, and Desert Research and Technology Studies (DRATS) mission environments
- Management of the Gateway to Astronaut Photography of Earth online database

Collecting an Antarctic Meteorite



Imagery Management Software

Genesis Laboratory

Science Consulting Services

Education Outreach and Training

Packaging and delivery of scientific and technical information for curriculum development, staff training, continuing education, and public outreach in hardcopy, digital, and presentation formats.

Applications

- Training in a variety of Earth system science topics related to orbital handheld camera photography
- Training in geology, geophysics, remote sensing, oceanography, and climate science
- K-12 classroom and distance-learning presentations on a wide variety of topics related to planetary geoscience and human exploration activities
- Teacher workshops, learning events, and K-12 curriculum development
- Mentoring of interns, graduate students, and postdoctoral researchers
- Design and deployment of online informational and teaching modules and interactive “citizen scientist” data entry portals

JSC Experience

- Expedition Earth and Beyond program links astronaut photography of Earth to authentic student-led research
- Lunar and Meteorite disk program provides sample material for classroom use
- Collaborative intern and visiting lecturer programs engage students
- Crew Earth Observations astronaut training in geography, Earth science, and photography

Conducting Education Outreach and Training for Students, Interns, and Educators

Science Consulting Services

Science Mission Planning

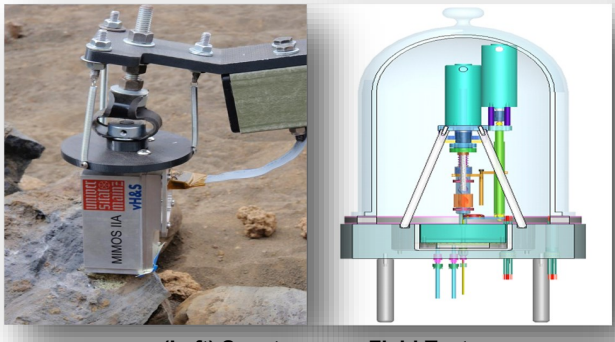
JSC provides planetary mission planning expertise in the areas of science instrument development and testing, science payloads, in-situ measurements on planetary surfaces, and analysis of returned samples. JSC continues to have a leading role in enabling science from past missions, in current robotic missions to Mars, in future asteroid sample return missions, and in instrument concept development and testing. JSC also provides comprehensive analog field expedition planning.

Applications

- Fully integrated science and engineering instrument development services, prototype fabrication, and laboratory testing
- Laboratory testing of robotic flight instruments, including spectroscopy and mass spectrometry, using relevant geosciences sample libraries
- Field science services, including expedition and traverse planning, crew training in geosciences and sample collection, real-time and remote science operations, strategic and tactical science team training and support, and development and implementation of integrated field data and image databases with operational software
- Concept development for missions to near-Earth objects (asteroids), robotic sample missions, *in-situ* analysis missions, and sample handling tools for future human missions
- Concept and technology development for sample handling and return missions to Mars, asteroids, and the Moon

JSC Experience

- Returned sample mission experience includes the Stardust comet and Genesis solar wind sample missions as well as the Apollo lunar missions
- Robotic planetary mission experience includes past and current Mars rovers, landers, and the Mars Science Laboratory mission
- Instrument development and testing includes instrumentation for past and current Mars Exploration Rovers and the Mars Science Laboratory as well as concept development for proposed future missions
- Analog field science expeditions include expeditions to the Antarctic to collect samples and to Chile, Hawaii, and Norway
- NASA Extreme Environmental Mission Operations (NEEMO) undersea analog mission



(Left) Spectroscopy Field Test
(Right) Soil Sampling Instrument Test Bed

Clockwise From Top Left: Traverse Planning, Astronaut Training and Robotic Field Tests, Habitats, NEEMO

Research and Analytical Services

JSC provides expertise in geoscience and material research and analysis through a wide range of high-precision imaging and spectroscopic instruments. Specialty instruments and techniques include scanning and transmission electron microscopy with chemical mapping, focused ion beam milling for micron- and nanoscale sample preparation, electron microprobe elemental mapping, elemental and isotopic mass spectrometry across the entire periodic table, organic mass spectrometry of complex molecules from micron-scale samples, X-ray diffraction for mineralogy, evolved gas analysis of volatiles from returned samples, and analogs and *in-situ* measurements on planetary missions. JSC also has the unique capability of doing "correlated analysis" of micron-scale and nanoscale samples using multiple instruments to produce multidimensional spectral data and imaging.

Scanning Electron Microscopy – Focused Ion Beam

FTIR Spectroscopy

Light Element Mass Spectrometry

Field Emission Scanning Electron Microscopy

Scanning Electron Microscopy

- Nano- to micro- to millimeter-scale imaging—both morphological and compositional imaging
- Non-destructive examination
- Chemical characterization—detection of elements from boron to uranium
- Chemical ping—distribution of elements can be imaged at the micro scale

Applications

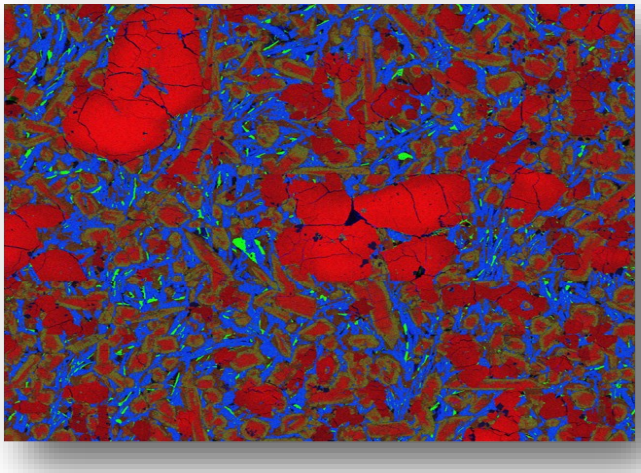
- Geoscience, materials science (metals, ceramics, alloys, electronic and magnetic materials, and cements), materials engineering, forensic science, and biological specimens
- Failure analysis

Tools

- Two scanning electron microscopes: JEOL 5910LV can accommodate larger samples; JEOL 7600FE is best at ultra-high resolution imaging
- Field emission (FE) SEM with four electron detectors can achieve imaging with nano-scale resolution
- FE-SEM optimized for low kV work, emphasizing near-surface features and improving spatial resolution
- Ultra-high count rate X-ray detector for chemical mapping of samples based on X-ray emission induced by bombardment with energetic electrons
- Carbon and metal coaters for preparation of nonconducting materials

JSC Experience

- Expertise in sample preparation, conductive coating for examination of non-conducting materials, instrument use, and data interpretation
- Expertise in technique selection; i.e., which method is needed to attack the problem. With a critical mass of methods [electron probe, SEM, FIB, TEM, and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and personnel with expertise in all of these methods, JSC can provide a rare level of knowledge of how to attack a problem, avoiding time spent using the wrong method and potentially exploiting the synergy of applying multiple techniques



This chemical map illustrates the distribution of elements in a Martian meteorite. Mg is red, Ca is green, and Al is blue. The same methods can be applied to metals, alloys, and ceramics. This type of elemental mapping can contribute to understanding the strength or characteristics of engineered materials.

Transmission Electron Microscopy

- Imaging and chemical analysis of the structure of materials on the nanoscale
- FIB sample preparation for nanoscale cross-sectional analysis of localized micron-scale sample regions
- Ultramicrotomy for analysis of particulate materials 1 micron in diameter and larger

Applications

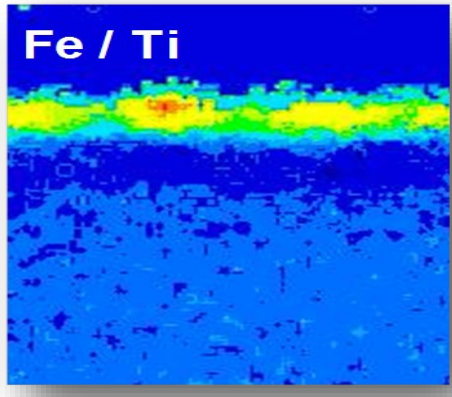
- Determining the structural properties of advanced metals, ceramics, polymers, and semiconductors for structural and electronic applications
- Analysis of nanotechnology and nanoparticles
- Materials processing quality control and root-cause defect identification
- Analysis of material coatings for chemical resistance, optical, and electronic properties
- Analysis of spacecraft and aircraft structural materials and sensors

Tools

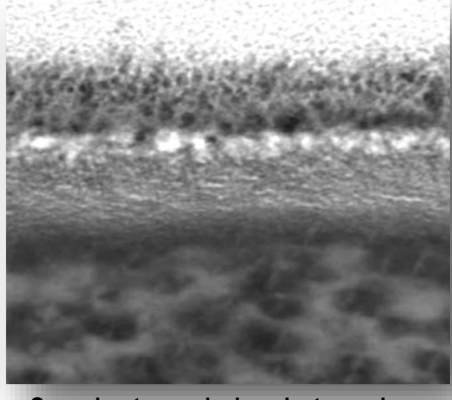
- JEOL 2500SE field-emission scanning transmission electron microscope
  - Direct imaging of the crystal structure of materials and associated extended structural defects on the sub-nanometer scale
  - Nanoscale quantitative mapping of chemical variations in solid materials resolved on the 10-nm scale
  - Nanoscale quantitative mapping of chemical bonding and oxidation state variations in solid materials
  - Analysis of cross-section regions of solid-state devices, layered materials, and coatings localized on the micron scale
- JEOL 2000FX analytical transmission electron microscope
  - Direct imaging of the crystal structure of materials and associated extended structural defects on the nanometer scale
  - Quantitative spot chemical analysis of chemical variations in solid materials on the 100-nm scale

JSC Experience

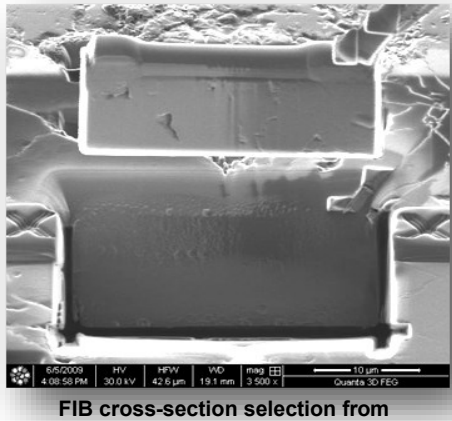
- Analysis of interplanetary dust particles collected from aircraft and Stardust comet particles
- Spacecraft Crew Survival Integrated Investigation Team (SCSIIT) reconstruction of Columbia's materials damage profile during breakup on reentry
- Nanoscale characterization of electronic materials and devices
- Structural and chemical characterization of biomaterials (e.g., microbes and viruses)



X-ray spectroscopy chemical maps show quantitative variations in chemical composition



Scanning-transmission electron microscope imaging shows ion-processed layers at surface of Fe-Ti oxide crystal



FIB cross-section selection from crystal surface

Research and Analytical Services

Focused Ion Beam

- Dual-beam (ion and electron beam) FIB is an extremely versatile technique for micro and nanoscale machining
- Built-in field-emission gun (FEG) SEM combined with micro/nano machining and fabrication capabilities incorporates a high-energy ion beam able to deposit various materials (e.g., carbon and platinum) and loaded with various detectors (e.g., SED, BED, X-ray) for onsite analyses

Applications

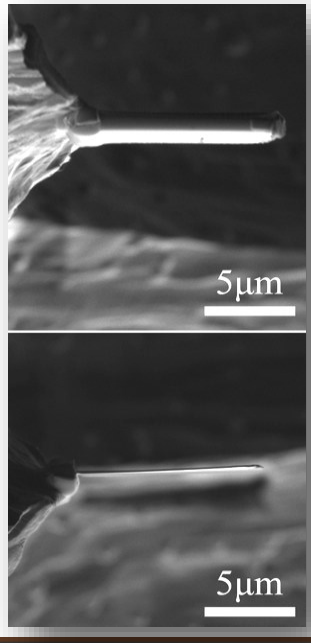
- Specimen preparation for NanoSIMS, SEM, microprobe, Auger Electron Spectroscopy (AES), and TEM/STEM (ultra-thin cross sections of less than 50 nm)
- Nanofabrication (dual-beam FIB)
- Ion channeling contrast imaging (e.g., grain-size analysis)
- Device modification (e.g., integrated circuit editing/debugging, micron-size bimetal devices/sensors) and micromachining (e.g., trimming Atomic Force Microscopy (AFM) tips, drilling patterns to make optical gratings and optical lenses)
- Onsite X-ray Energy Dispersive Spectroscopy (XEDS) analysis
- Biological, materials science, and life-sciences applications

Tools

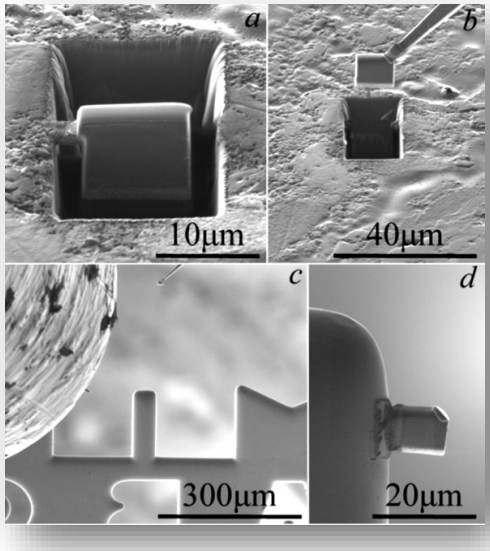
- FEI dual beam, FIB QUANTA 3D-FEG, featuring slice with FIB and view with SEM, *in-situ* cross section etch and coating, electron/ion beam metal deposition for protection, and super-thin TEM sample preparation

JSC Experience

- Sample preparation, including thin cross sections for TEM/STEM, cross sections for microprobe, SEM, and NanoSIMS for a wide variety of research groups and applications (e.g., presolar grains, meteorites, and lunar samples)



The section is thinned from ~2 microns in width to electron transparency (~100nm) for TEM analysis.



FIB-SEM preparation of an electron transparent thin section.
A) The material surrounding the area of interest is milled away.
B) The section is welded to a needle, detached from the substrate, and lifted out.
C) The section is transported to a copper TEM grid.
D) The section is welded to the TEM grid, and detached from the needle.

Research and Analytical Services

Electron Microprobe

- Precise spot analyses of major and minor elements of solid materials
- Quantitative imaging of major and minor elements of solid materials

Applications

- Determining the composition of natural or experimental minerals, glasses, metals, and alloys
- Determining the composition of materials, such as ceramics, thin films, and superconductors
- Compositional mapping of multiphase materials
- Applications in geology, material science, and superconductivity

Tools

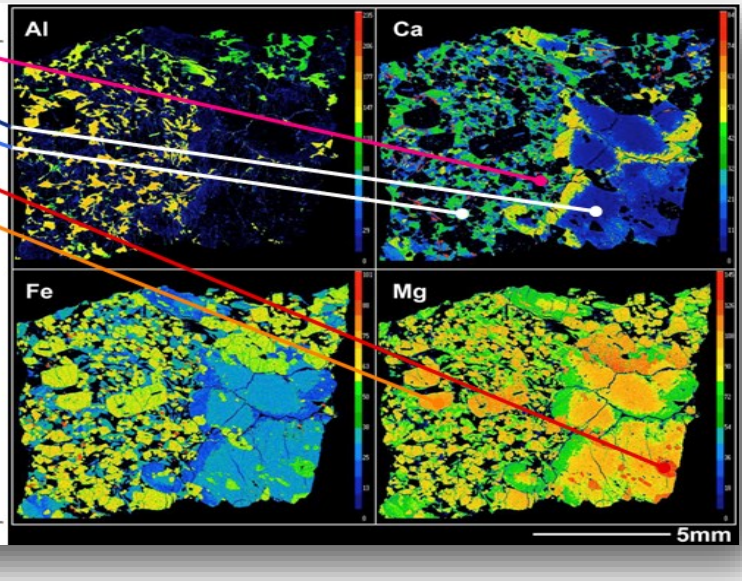
- Electron beam as small as 1 micron for point analysis as well as raster analyses
- Five wavelength dispersive X-ray spectrometers for simultaneous analysis of five elements
- Energy dispersive X-ray spectrometer for quick identification of phases
- Automatic stage setting for programming points and maps
- Reflective light, secondary electron, and back scattered electron imaging

JSC Experience

- Space Shuttle damage assessment
- Meteorite, Apollo lunar sample, and Earth rock analysis
- High-temperature and/or pressure and experimental impact sample analysis

	Olivine	Olivine	Pyroxene	Pyroxene	Phosphate
SiO_2	36.44	38.30	52.88	54.50	4.36
TiO_2	0.02	0.02	0.27	0.12	
Al_2O_3	0.04	0.04	1.32	0.78	5.30
FeO	33.47	26.76	11.08	16.42	1.07
MnO	0.77	0.64	0.51	0.64	0.09
MgO	29.65	34.56	17.58	25.23	2.86
CaO	0.30	0.20	15.88	2.40	39.63
Na_2O	0.02	0.02	0.21	0.05	2.18
K_2O	0.00	0.00	0.01	0.01	0.02
P_2O_5					41.71
SO_2					0.29
F					0.02
Total	100.70	100.55	99.74	100.15	97.54

Examples of Major Element Compositions of Minerals in a Martian Meteorite obtained with the Cameca SX100 Electron Microprobe at JSC



Elemental Map of a Martian Meteorite Thin Section Obtained with Cameca SX100 Electron Microprobe at JSC

Mass Spectrometry

Precise measurements of stable and radiogenic isotopes.

Applications

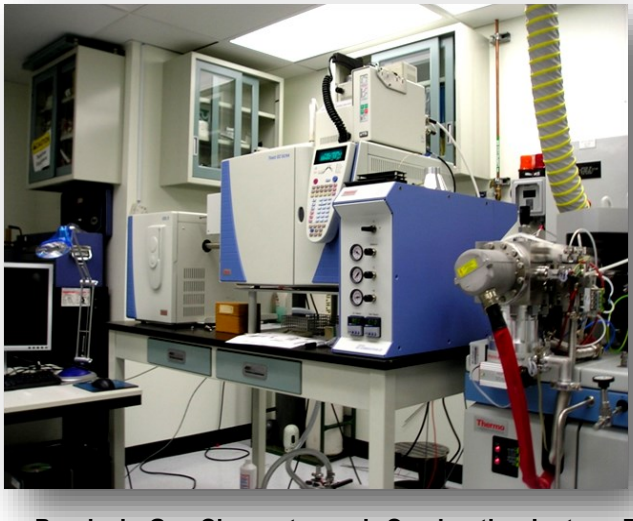
- Measurement of oxygen and hydrogen isotope tracers of metabolic processes for bioastronautics microgravity measurements
- Calcium isotope measurements as tracers of human bone loss caused by exposed to microgravity
- Oxygen and hydrogen isotope measurements of water vapor by laser diode wavelength modulation spectroscopy

Tools

- Thermo Electron MAT 253, MAT 262
- Triton multicollector TIMS
- Los Gatos water vapor isotope analyzer

JSC Experience

- Double-labeled water measurements
- Calcium isotope measurements
- Water vapor isotope measurements



Pyrolysis-Gas Chromatograph-Combustion-Isotope Ratio Mass Spectrometry (Py-GC-C-IRMS) apparatus used for high precision compound specific isotope ratio measurements of carbon, oxygen, and hydrogen

X-Ray Diffraction

Determining the arrangement and spacing of atoms in crystalline materials.

Applications

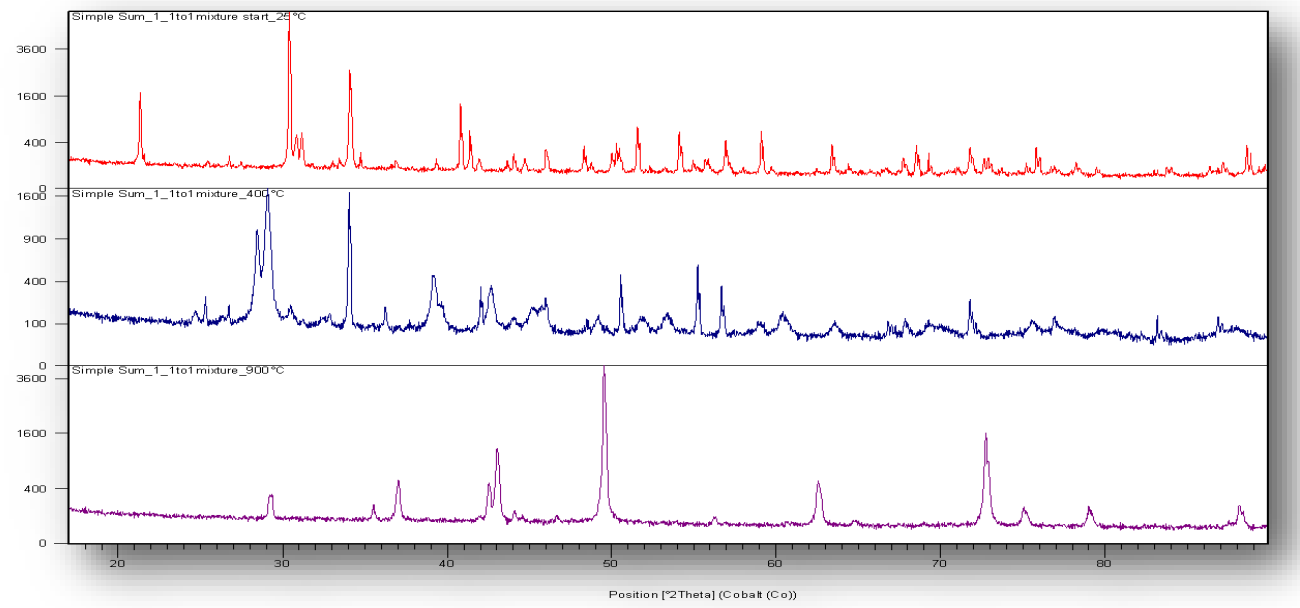
- Determining the mineralogy of soil and rock
- Assessing atomic arrangement of any powdered material at temperatures of -190 to 900 °C
- Characterizing crystalline materials through Rietveld refinement
  - Quantifying the distribution of crystalline material
  - Determining the crystal size
  - Determining the crystal strain

Tools

- Panalytical X'pert Pro Modular Powder Diffractometer (MPD) powder XRD unit
  - Accelerator detector (2.12° scan window)
  - Anton Parr nonambient stages (10^{-2} to 1000 mbar)
    - XRK 900 25 to 900 °C
    - TTK 450 -190 to 450 °C
    - THC humidity stage 1 to 100 percent relative humidity, 25 to 50 °C

JSC Experience

- Quantitative mineralogical analysis of Atacama and Antarctic soils
- Thermal (25 to 900 °C) phase change analysis of Mars analog materials
- Database development for CheMin, a Mars XRD instrument flying on the Mars Science Laboratory rover Curiosity



XRD Can Monitor Crystalline Phase Changes as Function of Temperature

Mars, Moon, Meteorite Evolved Gas Analysis Laboratory (M^3EGA)

- Thermal and evolved gas analysis of geologic materials
- Thermal and evolved gas analysis of any solid or powdered material

Applications

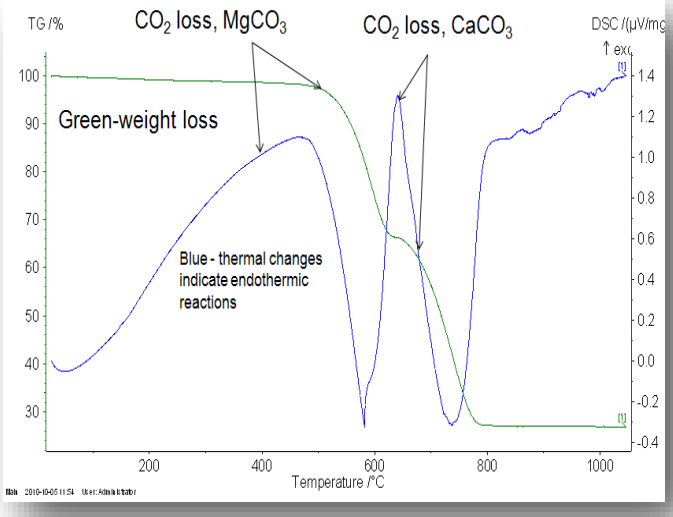
- Determining thermal decomposition properties of solid or powdered material
  - Exothermic and endothermic decomposition temperatures can be assessed
  - Thermal gravimetric capability can measure weight loss associated with thermal changes
  - Coupled mass spectrometers can assess temperatures of corresponding gas and volatile release from decomposing materials
- Assessing thermal decomposition properties from -120 to 1500 °C and 10^{-2} to 1000 mbar

Tools

- Thermal analytical instruments
  - Setaram Ligne 96 (25 to 1400 °C)
    - Heat-Flux differential scanning calorimeter 1400 probe
- Thermal gravimetric probe
  - Setaram Sensys-Evo (-120 – 833°C)
    - Heat-flux differential scanning calorimeter probe
  - Netzsch Simultaneous Thermal Analyzer (STA) 449 F1 Jupiter
    - Combined thermal gravimetric differential scanning calorimeter probe
- Mass spectrometers
  - Pfeiffer
    - ThermoStar Benchtop Gas Analysis System GSD320 T3
    - ThermoStar GSC301 T
  - Stanford Research Systems Universal Gas Analyzer (UGA) 300

JSC Experience

- Mars missions
  - Thermal Evolved Gas Analyzer Phoenix landing site
  - Sample Analysis at Mars (SAM) Mars Science Laboratory
- Thermal and evolved gas analysis database development for Mars missions
- Mars mission data interpretation



$MgCO_3$ and $CaCO_3$ Decomposition Observed by Netzsch DSC-TGA Probe

Organic Microprobe: Two-Step Laser Mass Spectrometry (μL^2MS)

- *In situ* trace organic analysis of particulates and heterogeneous samples at high spatial resolution
- Sub-femtomole (< 10^{-18} M) detection limits for aromatic and/or conjugated organics
- Variable spatial resolution down to 5 mm spot size
- Nondestructive analysis with no sample preparation necessary
- Single-point or spatial mapping analysis with complete mass spectrum at each pixel
- Resonance-enhanced multiphoton ionization scheme to minimize molecular fragmentation

Applications

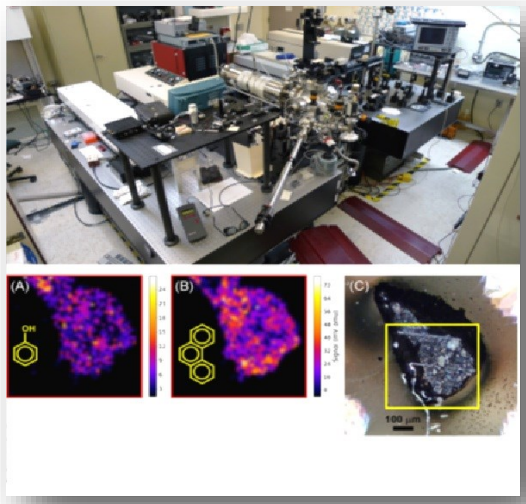
- μL^2MS has been used in pure and applied research in both academia and industry
- Astromaterials research has included the analysis of meteoritic acid residues, carbonaceous and ordinary chondrites, Antarctic micrometeorites, interplanetary dust particles, interstellar graphite grains, laboratory synthesized interstellar ice residues, Stardust cometary dust particles, Apollo lunar rocks, and Martian meteorites
- Applied aerospace studies have involved analysis of spacecraft organic contamination (e.g., Stardust and Genesis) and effects of thermal ablation on phenolic impregnated carbon ablator heat shield (Stardust)
- Industrial research studies have included environmental pollution resulting from pesticides (e.g., 2,3,7,8-Tetrachlorodibenzo-p-dioxin), industrial waste from high voltage transformers (e.g., polychlorinated biphenyls), chemical weapons residues (e.g., organophoshate nerve agent), and incinerator wastes (e.g., benzo[a]pyrene)
- Biomedical and pharmaceutical research studies have included analysis of lung tissue from smokers and forensic analysis of drug contamination in a manufacturing facility

Tools

- The μL^2MS instrument consists of three main components
  - Nonthermal CO_2 laser IR desorbtion source
  - Multiphoton Ultraviolet (UV) ionization source using either nanosecond or picosecond frequency quadrupled Nd:YAG lasers
  - Two-stage reflectron time-of-flight mass spectrometer equipped with large area "*hot*" microchannel plate detector assembly

JSC Experience

- Designed, built, and currently operating the μL^2MS system
- Employed vacuum systems, digital and analog electronics, laser design, and operation and software development extensively



Spatial distribution maps of phenol (A) and phenathrene (B) on a fresh cut interior surface of Tagish Lake. (C) Optical image of epoxy mounted sample with the mapped region shown by the yellow box. Note that the molecular distributions are both strongly heterogeneous and anticorrelated.

Research and Analytical Services

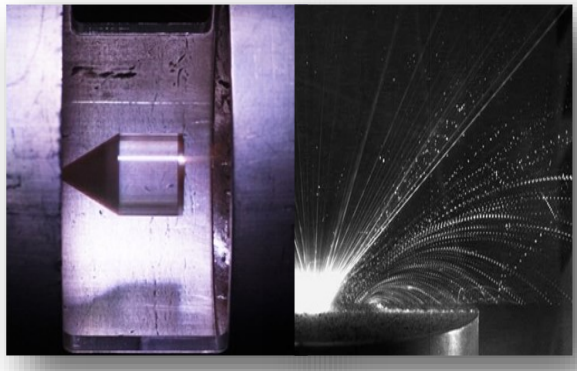
Experimental Impact Laboratory

The Experimental Impact Laboratory (EIL) contains three different accelerators, each of which can launch a variety of projectile types and sizes at targets of interest to address different aspect of the impact cratering process.

Experimental Impact Facility With the 1.7 km/s Flat Plate Accelerator (left) and the 6.5 km/s Two-Stage, Light Gas Gun (right)

Applications

- Flat-Plate Accelerator
  - Shock loading up to 700,000 atmospheres pressure to investigate shock metamorphism /alteration of natural geologic materials, including moon rocks and meteorites
- Vertical Impact Analysis
  - Impact and ejecta analysis in solid or noncohesive targets / materials
  - Crater growth and shape
- 5mm Light-Gas Gun
  - Particle capture / disruption studies
  - Hypervelocity impact studies



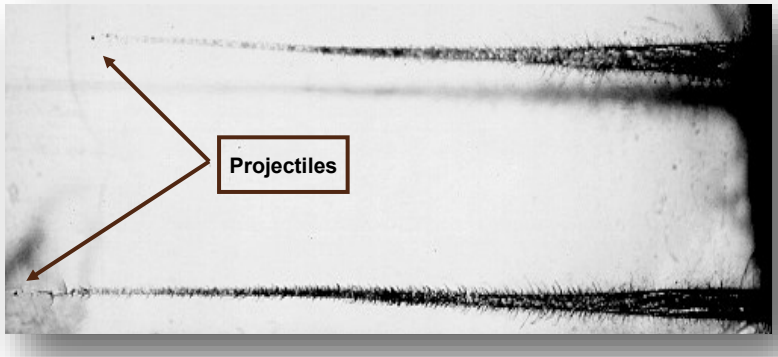
(Left) Flat Plate Accelerator Projectile Carrier in Flight Moments Before Target Impact at 1.7 km/s (Right) Vertical Impact Target Ejecta From a 3.18-mm Glass Sphere Projectile Into Coarse Sand at 1.26 km/s with Particle Tracks

Tools

- Flat-Plate Accelerator
- Vertical Impact Facility
- 5 mm Light-Gas Gun
- Machine Shop
- Experienced machinist and pyrotechnics staff / laboratory personnel
- Cold target preparation and experimentation

JSC Experience

- Light-Gas Gun used to test and flight qualify the Aerogel that flew on the Stardust cometary sample recovery mission
- Successfully measured the velocity of impact ejecta associated with an impact event to unconsolidated targets
- Comminution studies and the formation of regolith on planetary bodies



Hypervelocity Capture of 10 µm, Soda-Lime Glass Projectiles in Aerogel for Comet Capture Studies Using the Light-Gas Gun; Projectiles and Tracks Are Visible

Optical Measurement Center

The Optical Measurement Center (OMC) offers a state-of-the-art facility for photometric and spectroscopic laboratory measurements of natural and man-made materials or objects. The OMC simulates space-based illumination conditions using equipment and techniques that recreate telescopic observations and source-target-sensor orientations.

Applications

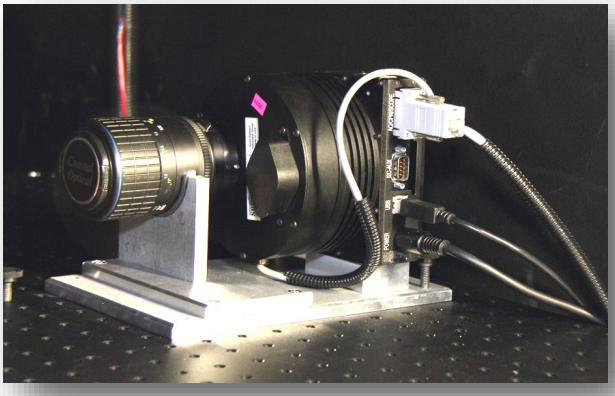
- Optical signature generation
- Bidirectional Reflectance Distribution Function (BRDF) measurements
- Spectroscopic measurements
- 3D scanner
- 3D printer creating high-fidelity models of natural and man-made objects, such as spacecraft and asteroids
- Large collection of spacecraft materials

Tools

- ASD field spectrometer: reflectance spectrometer with a spectral range of 300 nm to 2500 nm with 1-nm resolution
- SBIG CCD camera (1024x1536 pixels) with an automated five-position 1.25-inch filter wheel for ultraviolet, blue, green, red, and infrared filters
- Newport 75 W Xenon arc lamp simulates the solar illumination over the spectral range of 200nm to 2500 nm
- ST Robotics R17 robotic arm with 5 degrees of freedom
- Custom-built rotary arm with potentiometer

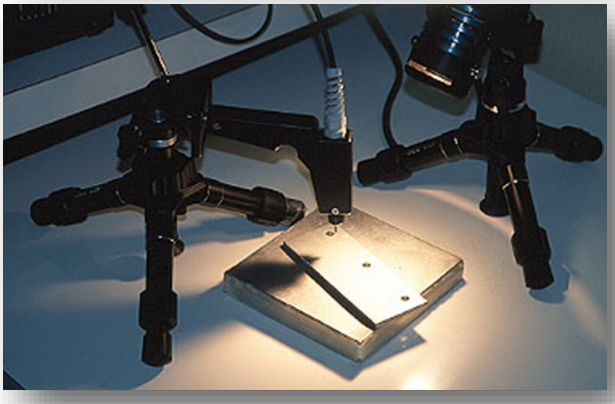
JSC Experience

- Initial capability established over 7 years using photometric and spectroscopic measurements in the laboratory
- Significant staff experience in laboratory and observatories



SBIG CCD Camera

Scaled Rocket Body Mounted on Robotic Arm



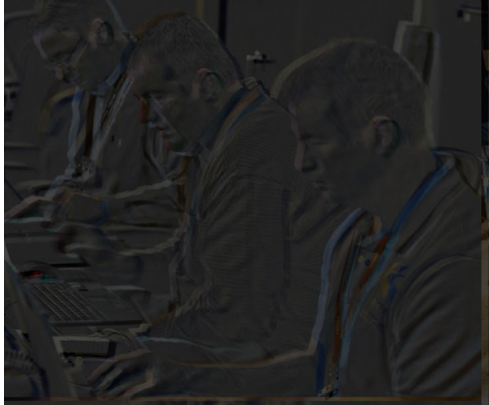
Spectrometer Pistol, Sample Material, and Quartz Lamp

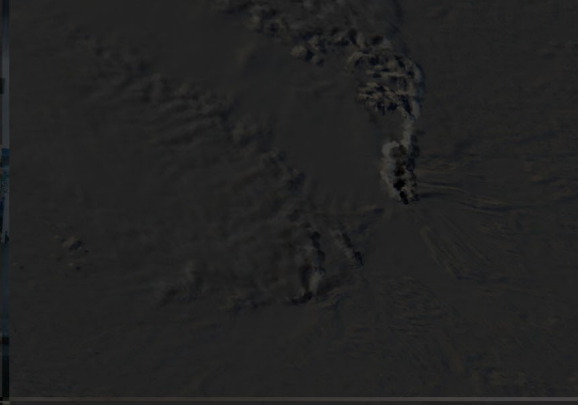
Acronyms

μL^2MS	Two-Step Laser Mass Spectrometry
2D	Two-Dimensional
3D	Three-Dimensional
4D	Four-Dimensional
6D	Six-Dimensional
AES	Auger Electron Microscopy
AFM	Atomic Force Microscopy
ARES	Astromaterials Research and Exploration Science
BRDF	Bidirectional Reflectance Distribution Function
CO_2	Carbon Dioxide
COTS	Commercial Orbital Transportation Services
CPAS	Capsule Parachute Assembly System
DOUG	Dynamic Onboard Ubiquitous Graphics
DRATS	Desert Research and Technology Studies
EAS	Early Ammonia Servicer
EDX	Energy Dispersion X-Ray
EIL	Experimental Impact Laboratory
EMU	Extravehicular Mobility Unit
FEG	Field-Emission Gun
FE	Field Emission
FIB	Focused Ion Beam
FLIR	Forward Looking IR Cameras
FTIR	Fourier Transform Infrared
GRAF	JSC Graphics Research and Analysis Facility
HVIT	Hypervelocity Impact Test
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
IIIMS	ISS Imagery Inspection Management System
iLIDS	International Low-Impact Docking System
IR	Infrared
ISCL	Inhibited Shaped-Charge Launcher
ISS	International Space Station
JSC	Johnson Space Center
LIBS	Laser-Induced Breakdown Spectroscopy
LiDAR	Light Detection and Ranging
M^3EGA	Mars, Moon, Meteorite Evolved Gas Analysis Laboratory
MEM	Meteoroid Environment Model
MMOD	Micrometeoroid and Orbital Debris
MPD	Modular Powder Diffractometer
MPLM	Multipurpose Logistics Module
NASA	National Aeronautics and Space Administration
NEEMO	NASA Extreme Environment Mission Operations
OMC	Optimcal Measurement Center
ORDEM	Orbital Debris Environment Model
SAA	Space Act Agreement
SAM	Sample Analysis at Mars
SCSIIT	Spacecraft Crew Survival Integrated Investigation Team
SEM	Scanning Electron Microscopy
SMAC	Simultaneous Multiframe Analytical Calibration
SSRMS	Space Station Remote Manipulator System

Acronyms

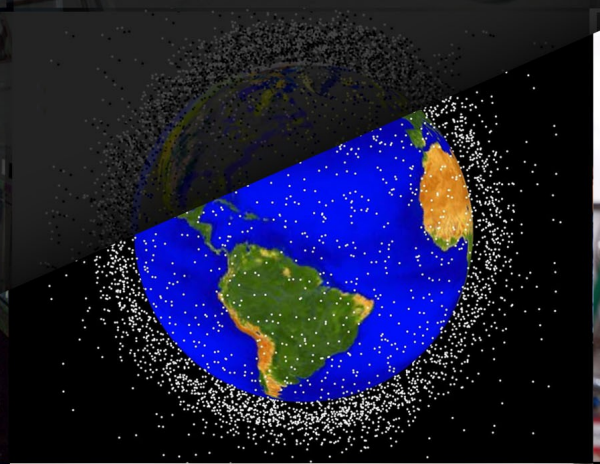
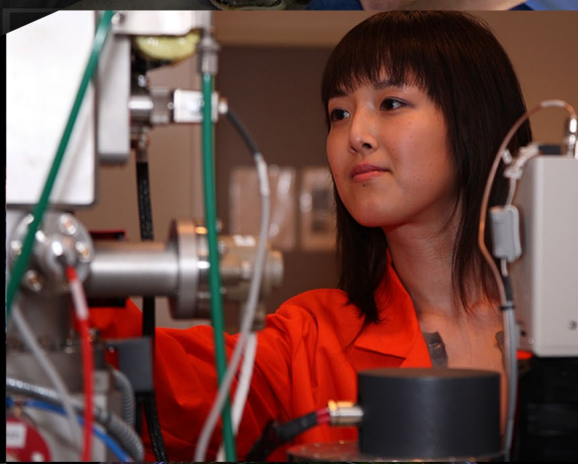
STA	Simultaneous Thermal Analyzer
SPH	Smoothed Particle Hydrodynamics
STEM	Scanning TEM
SwRI	Southwest Research Institute
TARDEC	Tank Automotive Research, Development, and Engineering Center
TEGA	Thermal Evolved Gas Analyzer
TEM	Transmission Electron Microscopy
TIIMS	TPS Imagery Inspection Management System
TPS	Thermal Protection System
UGA	Universal Gas Analyzer
UV	Ultraviolet
VSSA	Video Stanchion Support Assembly
WSTF	White Sands Test Facility
XEDS	X-ray Energy Dispersive Spectroscopy
XRD	X-ray Diffraction
XRF	X-ray Fluorescence





Silica



DEEP
SPACE
HABITAT
HYGIENE MODULE
Segment B
Segment A